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LONG PERIOD MICROSEISMS IN SOUTHERN NORWAY

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Bergen University

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Sea wave recordings from the Norwegian Coast and seismic recordings from the long period instruments of the Norwegian Seismic Array (NORSAR) and from the new broad band long period instruments at Kongsberg have been used to study the characteristics and the source locations of long period microseisms in Southern Norway.

The disturbances associated with lows in the Lofoten-Vesterålen

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area normally generate large, regular wave packets (beats) of double frequency (DF), 0.12-0.16 Hz, microseisms at Kongsberg. High level of primary frequency (PF) microseisms, 0.05-0.09 sec - occurs when there is high sea wave activity on the coast.

Occasionally the sea waves at the West Coast of Norway are sufficiently long period to generate PF microseisms; in such cases a close correlation between the rise in sea wave amplitude and the PF microseisms level at Kongsberg has been found.

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FOREWORD

This research was supported by the Advanced Research Projects Agency of the Department of Defence and was monitored by the Air Force Office of Scientific Research under Grant AFOSR-72-2305.

ABSTRACT

Sea wave recordings from the Norwegian Coast and seismic recordings from the long period instruments of the Norwegian Seismic Array (NORSAR) and from the new broad band long period instruments at Kongsberg have been used to study the characteristics and the source locations of long period microseisms in Southern Norway.

The disturbances associated with lows in the Lofoten - Vesterålen area normally generate large, regular wave packets (beats) of double frequency (DF), 0.12-0.16 Hz, microseisms at Kongsberg. High level of primary frequency (PF) microseisms, 0.05-0.09 sec - occurs when there is high sea wave activity on the coast, but it is not possible to explain a rapid increase in the PF microseisms level by a corresponding increase in the coastal sea wave activity. The PF microseisms source area seems to be more concentrated (in azimuth) than the DF source area.

Meteorological disturbances in the British Isles - Iceland area often generate large PF microseisms and moderate, irregular DF microseisms. It is not clear whether this is due to the generation mechanism or the transfer characteristics (frequency selective transfer function from oceanic to continental zone).

Occasionally the sea waves at the West Coast of

Norway are sufficiently long period to generate PF microseisms, and in such cases we have found a close correlation between the rise in sea wave amplitude and the PF microseisms level at Kongsberg.

LIST OF ILLUSTRATIONS.

INTRODUCTION

After the introduction of large arrays in the mid sixties, a number of papers describing the structure of microseisms appeared in the literature (Toksöz and Lacoss 1968, Capon 1969b, Haubrich and McCamy 1969, Bungum and al. 1971). In these papers attempts were also made to determine the source areas. However, when dealing with seismic energy propagating as surface waves, single array analysis can only give information of the direction to the source and the local velocity. To locate the source areas one needs multi-array analysis and/or other information that can be correlated with the seismic readings. Various reports have originated associating microseisms with ocean to land passage of cold fronts, lows at open sea, wave action on coast lines with varying coastal efficiency etc. (Båth 1949, Darbyshire 1950, Donn 1952, Toksöz and al. 1968, Kulhanek and Båth 1972). The problem of using "other information" (sea wave measurements, weather maps etc.) is essentially that the lack of resolution of the information in time and space makes it very difficult to perform and interpret the correlation analysis. Also, very often the earth's background noise level changes so slowly that it is hard to separate one possible cause from another.

A possible way to overcome some of these uncertainties is to search the seismograms for situations with very rapid and dramatic changes in the noise level or the noise character for closer examination. By comparing with other information available one may then be able to establish the degree of hour-to-hour correlation between possible causes for and the actual readings of the earth's movements.

DATA AND DATA ANALYSIS

The seismic data used in this study are the long period digital recordings from the Norwegian Seismic Array - NORSAR - with system peak response at about 20 sec, and the paper recordings from the Kongsberg broad band High Gain Long Period (HGLP) instruments.

From the array data the power spectral density of the noise field can be estimated, giving the power density as a function of local velocity, frequency and direction of propagation (Capon 1969 a).

The HGLP system at Kongsberg has in addition to high magnification the advantage of recording in two frequency bands, and this property has turned out to be a very good aid in characterizing the noise structure. The response curves for the vertical components of the HGLP systems - ZHI and ZLO - are shown in Fig. 2. As one can deduce from the figure the High-gain components are particularly sensitive to the PF microseisms, while the Low-gain components respond very well to the DF microseisms.

The sea wave activity on the Norwegian Coast has been studied using the wave recordings from Halten (ocean depth 140 m) and Utsira (ocean depth 100 m) (Fig. 1).

The continuous sea wave recordings were digitized with a sampling interval of 1 sec and the power density spectra were estimated by direct transformation and averaging nonoverlapping data blocks. The individual blocks were weighted using a Bartlett data window. The number of samples in each data block and the number of blocks used in the computations are given on top of the figures.

The weather maps shown in the report have been prepared by the weather forecast bureau in Bergen, "Vær-varslinga på Vestlandet". In the following we present some

situations selected according to the criteria listed above, and discuss the seismic noise recordings of Kongsberg in view of the frequency-wavenumber (f-k) spectra of NORSAR and - when available - the coastal sea wave spectra.

19 OCT. 1972.

The noise level is moderate on both Kongsberg LPZ-components until about 1000 hrs. From that time there is a rapid increase in the amplitudes, most pronounced on the High-gain component (Fig. 4). The dominating period on this recording is about 17 sec, corresponding to the frequency termed primary frequency by Haubrich and McCamy (1969). According to Hasselmann's theory (Hasselmann 1963) this could be due to the direct sea wave action on the coast.

The NORSAR wavenumber plots (Fig. 6) show arc noise from NW. The direction to the intensity maximum does not change significantly neither with frequency nor with time.

The NORSAR LPZ power spectra (Fig. 7) follow the same trend as do the Kongsberg recordings. During the time period 0900-1400 the DF microseisms show the strongest increase; from about 48dB at 0900 to 64dB at 1400. The meteorological situation is dominated by a low in the Lofoten-Vesterålen area, and strong winds on the Northwest coast of Norway. The coldfront associated with the low moves very fast across the southern part of Norway (although this happened before the great changes in the noise level appeared).

A sea wave spectrum at Halten is shown in Fig. 5. As we can see there are nochanges in the sea wave level between 0500 and 1100. Calculations performed between these two points of time confirm this result. In this connection we remind of Haubrich's and McCamy's conclusions: "PF-surface wave noise generation can be explained by ocean waves near the coast". As will be shown later this is also our conclusion for other situations

by other coastlines, but for this particular situation we do not find that the sea wave analysis and the f-k analysis give any explanation of the sudden increase in the PF microseismic level.

Finally we note that the DF microseisms which is subject to a more gradual increase, consists of regular wave-packets.

6 NOV. 1972.

There is a clear change in the noise level between 1800 and 2000 hrs, with increasing amplitudes of the 17-18 sec periods (Fig. 9). According to the wavenumber spectrum (Fig. 11) this energy is received in a very narrow sector, and the direction of arrival changes slowly from NW at 1300 hrs to W at 2100 hrs. During this period of time there is a rise in the noise level, most conspicuous for the low frequencies (Fig. 9). The Low-gain recordings show moderate noise level with irregular structure (the classical wavepackets with smoothly varying envelopes are missing).

By comparing with the sea wave spectrum at Utsira, some indications of the location of the source area can be given: We have observed that while the High-gain noise level increases, the sea wave activity at Utsira decreases. Also, by comparing the sea wave spectra of 5 Nov. and 6 Nov. with the corresponding seismic recordings (Figs. 9 and 10), we find that the highest sea wave coastal activity corresponds to the lowest microseismic activity. From these findings and the wavenumber analysis we conclude that the PF microseisms 6 Nov. 1972 hardly is generated on the Norwegian coast.

A low of 965 mb is located between Iceland and Greenland in the beginning of the period, and moves eastwards (Fig. 8) during the time period of interest. The associated fronts move across the NORSAR area, but since the noise level increases after the passage of these fronts it is hard to believe that the fronts are responsible for the earth movements. Furthermore, the energy is well defined as propagating waves from the west.

The generating area must therefore be located in the North Atlantic ocean further to the west, but it is not possible from the information available to specify the relative contribution from open sea areas or coastal areas.

It is very interesting to pursue the development of this situation a bit further and see what happens when the long period sea waves start to grow at Utsira (Figs. 12 and 13). In Fig. 13 the sea wave power spectra for three different times are plotted, and the seismograms covering the same time periods are shown in Fig. 12. The maximum sea wave level on Utsira on 5 Nov. 0830 and 7 Nov. 1130 is nearly the same, but in different frequency ranges. Apparently the high frequency sea wave activity on the coast is not able to generate any substantial amount of microseismic noise while there is a good correlation between the long period sea wave level and the PF microseismic level.

15-16 JAN. 1973.

Weather maps on Fig. 14. This is the second example in the collection with moderate noise level on the Low gain and high noise level on the High gain component. As in the preceding example, the High gain

recording seems to be narrow band, while the typical wave packets are missing on the Low gain recordings (Fig. 15).

The sea waves at Utsira (Fig. 16) are not very large, but there is an increase in the amplitude of the long period waves with time, which can be responsible for part of the PF microseisms at Kongsberg. It is not probable, however, that a major part of the microseismic activity is due to the sea wave action in the Norwegian west coast.

The wavenumber analysis (Fig. 17) shows arc noise propagating from W in the first part of the period and NW at a later stage.

The noise character of this situation differs markedly from the noise character of 4-5 April, and these two examples form an excellent demonstration of the advantages by recording in two frequency bands.

2 FEB. 1973.

This situation reminds of the situation on 19 Oct. 1972. A 970 mbs low is located in the Lofoten-Vesterålen area, while the corresponding fronts move towards East across Norway (Fig. 18). At 1500 hrs the coldfront has reached the coast of Norway, and the air pressure gradients over the Norwegian sea have increased relative to the gradients at 0900 hrs. The microseismic energy buildup starts at around 1500 hrs (Fig. 19) reaching a maximum at about 2200-2300 hrs. The power level is characterized by rapid changes, and there is a very similar rate of buildup and decay at both Kongsberg components, although slightly more pronounced on the High-gain.

This is in accordance with what was found for 19 Oct. 1972, and contrasting to the noise character resulting from meteorological disturbances in the British Isles - Iceland - Greenland area (6 Nov. 1972).

The wavenumber spectra (Fig. 20) show noise sources to the North and Northwest. This is true for all frequencies. Note the changes in the azimuthal power distribution at 0.05 Hz, from nearly isotropic noise at 0800 hrs to an eventlike (point) source at 1700 hrs. Another interesting point is the apparent separation into two well defined energy sources as the frequency changes from 0.06 Hz to 0.067 Hz.

The increasing sea wave activity on the West Coast is illustrated by two Utsira power spectra (Fig. 21).

4-5 APRIL 1973.

In the beginning of the period a low pressure zone extending from Scotland to Greenland produces winds from S and SE in the southern Norwegian Sea. The remnants of a low is located near the Lofoten islands (Fig. 22).

Towards the end of the period the eastern end of the low pressure zone is turning to the North, resulting in winds from W on the west coast of Norway and winds from E in the northern Norwegian Sea.

The development of the earth noise as recorded by the two broad band LPZ instruments at Kongsberg is quite different in the different frequency bands. During the entire period the ZHI shows moderate noise level with small changes. At ZLO there is a strong increase in the noise level from 0800 hrs on 4 Apr., and during the time of increasing microseisms there is

also increasing sea wave activity at Utsira (Fig 25), with a dominating period of 10 sec, and very little energy at longer periods. Consequently one would not expect very much low frequency seismic energy be generated by the coastal sea wave activity and this is also corroborated by the seismic recordings.

By inspecting the wavenumber spectra we find only isotropic noise at the low frequencies (Fig. 26) and broad arc noise from NW in the DF band (Fig. 27).

It is not surprising that the DF noise is covering a large azimuthal range (the 6dB contours extend to about 1/4 of the periphery). In fact both the coastal sea wave activity (Figs. 24 and 25) and the wind areas in the Norwegian Sea suggest broad arc sources.

CONCLUSIONS.

The disturbances associated with lows in the Lofoten-Vesterålen area normally generate large, regular wave packets (beats) of double frequency (DF), 0.12-0.16 Hz, microseisms at Kongsberg. High level of primary frequency (PF) microseisms, 0.05-0.09 sec - occurs when there is high sea wave activity on the coast, but rapid increases in the PF microseisms occur without corresponding increase in the coastal sea wave activity.

Meteorological disturbances in the British Isles - Iceland area often generate large PF microseisms and moderate, irregular DF microseisms.

In some cases there is a good correlation between the long period sea wave activity at Utsira and the PF microseisms at Kongsberg, suggesting that the generating mechanism be wave action on the West Coast of Norway.

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Kulhanek, O. and M. Båth: Power spectra and geographical distribution of short-period microseisms in Sweden, Pure and Applied Geoph., Vol. 94, pp. 148-171, 1972.

Toksöz, M.N. and R.T. Lacoss: Microseisms, Mode structure and sources, Science, Vol. 159, pp. 872-873, 1968.

Fig. 1. Map showing the location of the sea wave recording stations Halten and Utsira, and the seismograph stations NORSAR and Kongsberg HGLP.

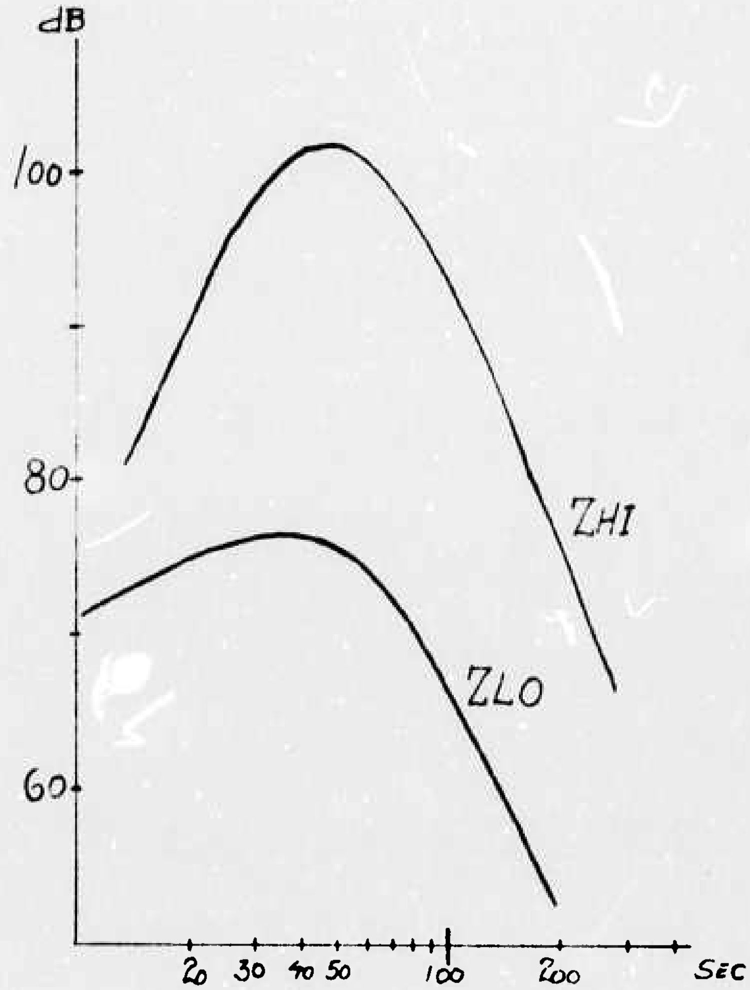


Fig. 2. Response curves for the two vertical components ZHI and ZLO of the Kongsberg broad band system.

0900 1200

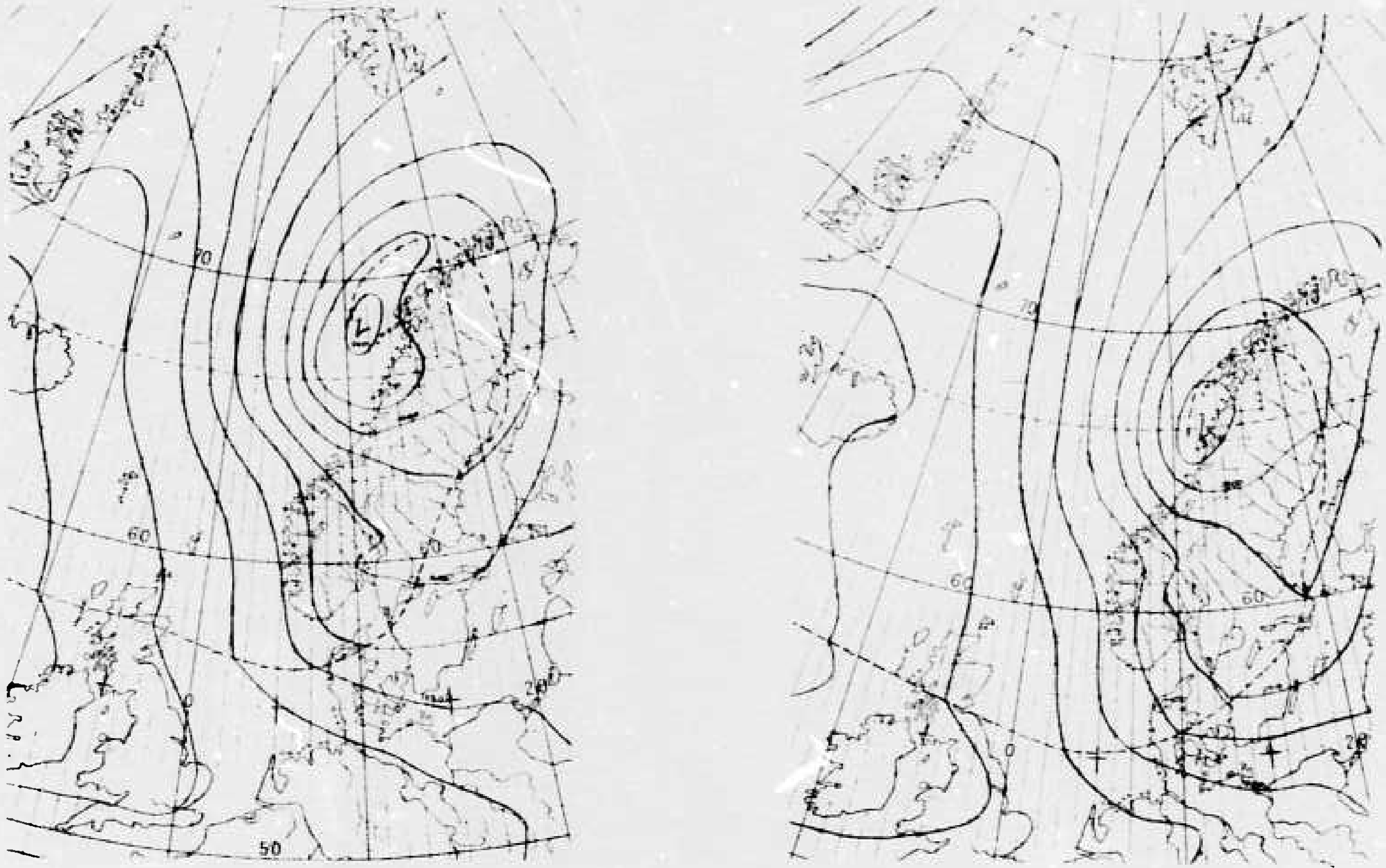


Fig. 3. Weather maps 19 Oct. 1972, 0900 and 1200.

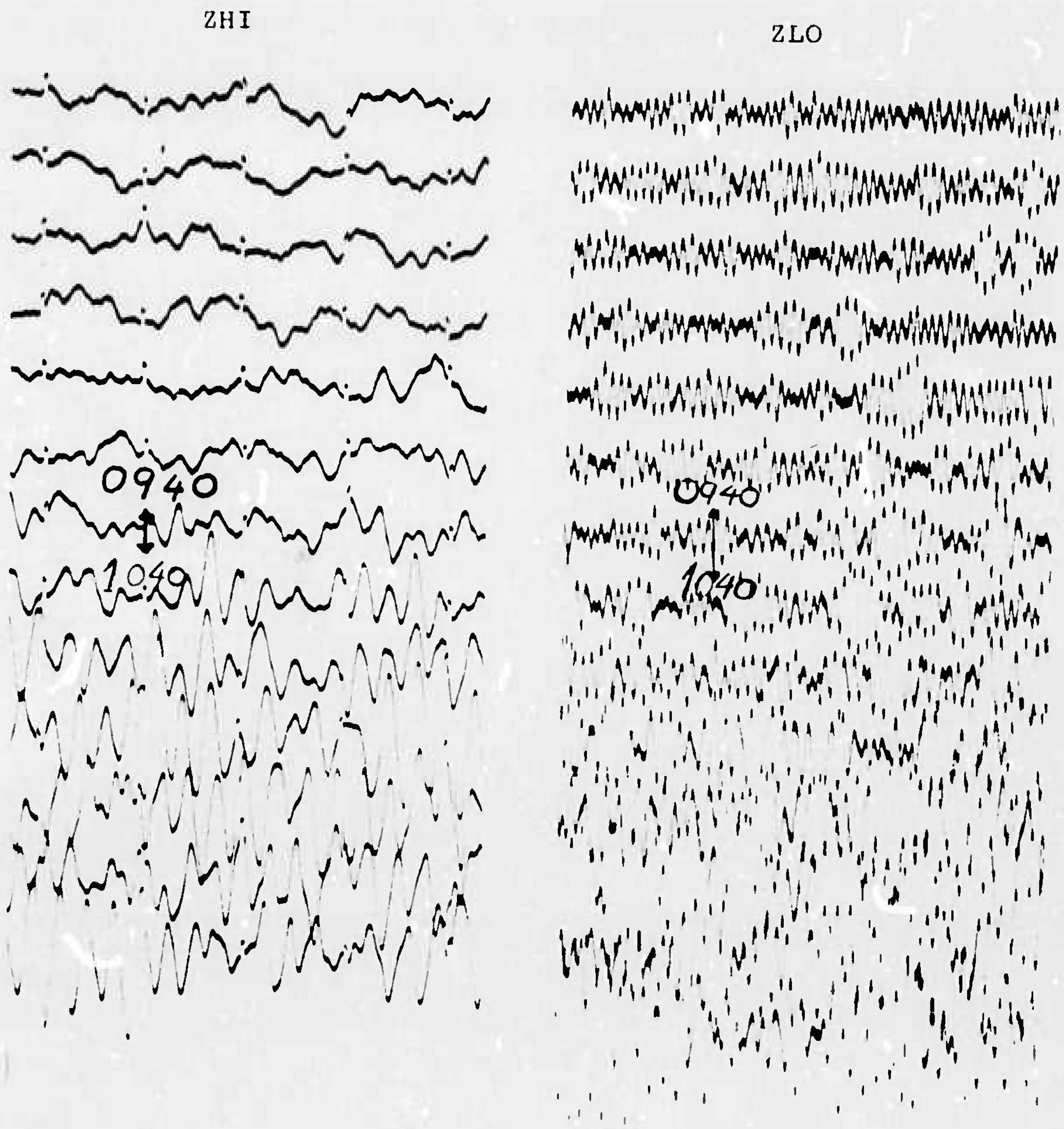


Fig. 4. LPZ-seismograms from the broad band instruments at Kongsberg 19 Oct. 1972. High gain recording to the left.

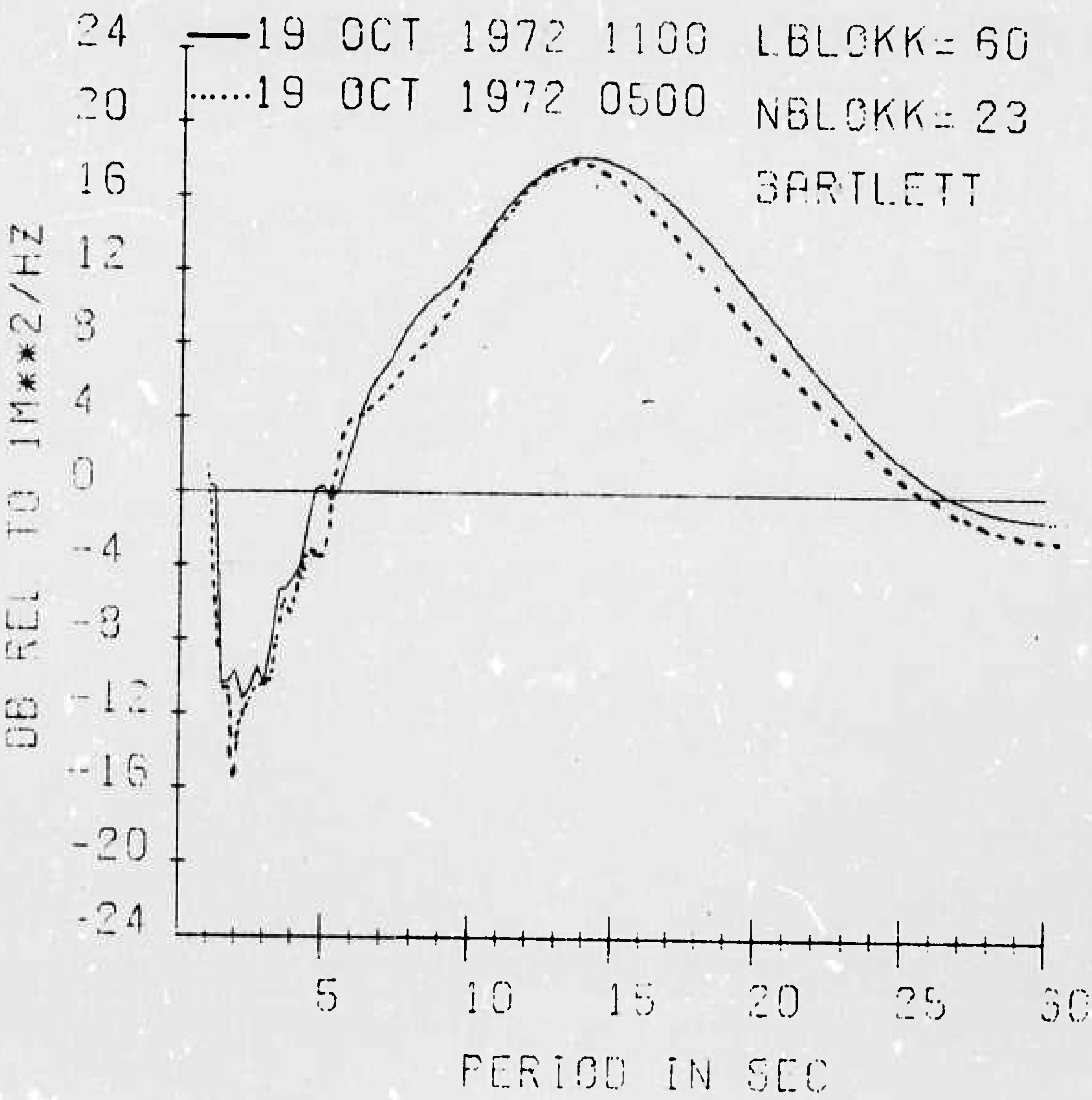


Fig. 5. Sea wave spectrum at Halten 19 Oct. 1972, 0500 and 1100. For this and the following sea wave power spectral plots: LBLOKK gives the number of samples in each data block and NBLOKK gives the number of blocks used in the power spectrum computation.

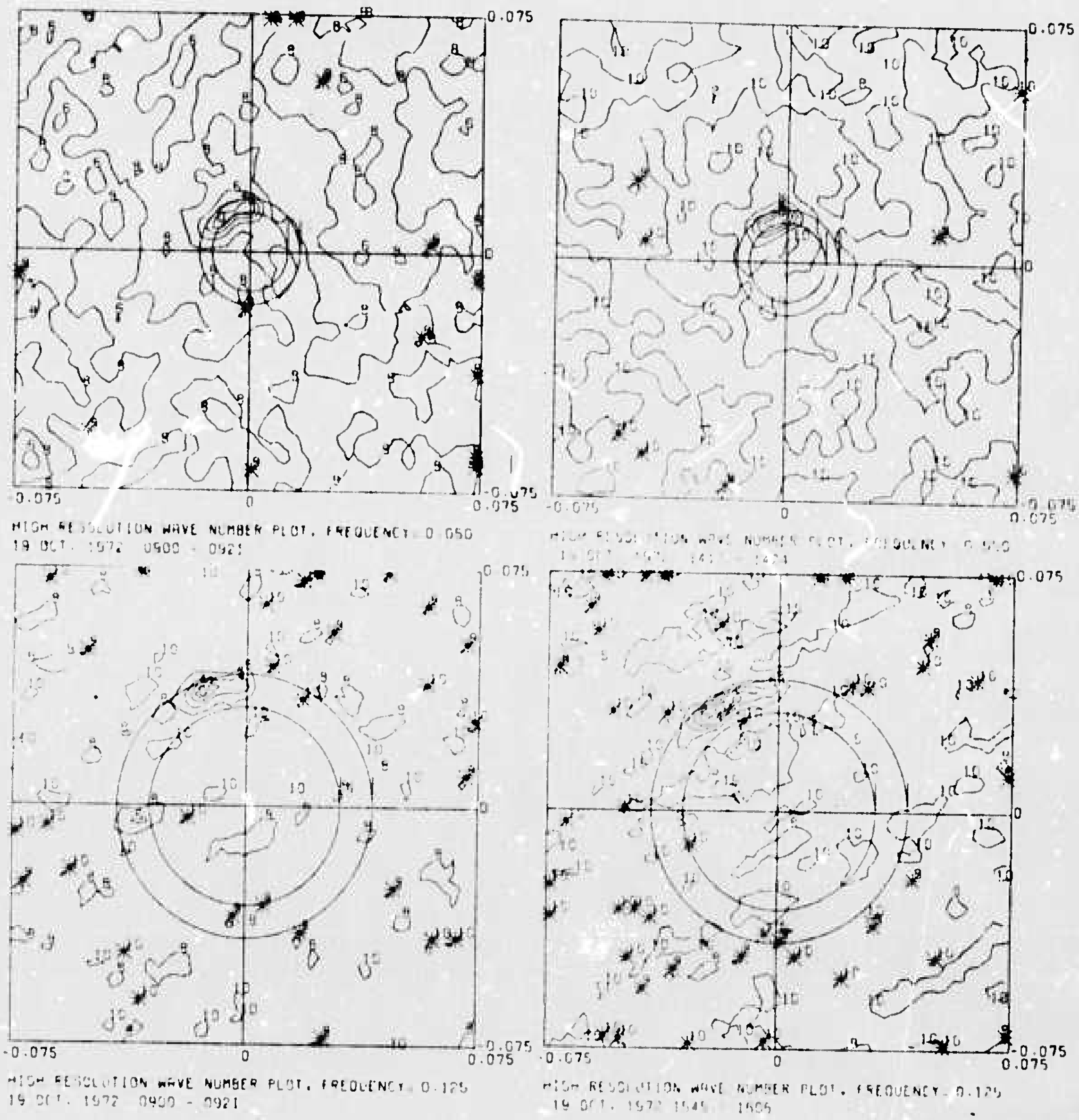


Fig. 6. NORSAR LPZ wavenumber spectra 19 Oct. 1972 at frequencies 0.050 Hz and 0.125 Hz.
For this and the following wavenumber plots:
The axes represent horizontal wavenumber (c/km).
The power estimates are based on 5 blocks á 256 samples of 1Hz data. The circles represent velocities of 4 km/s (inner ring) and 3 km/s respectively. The contour levels are in dB down from maximum.

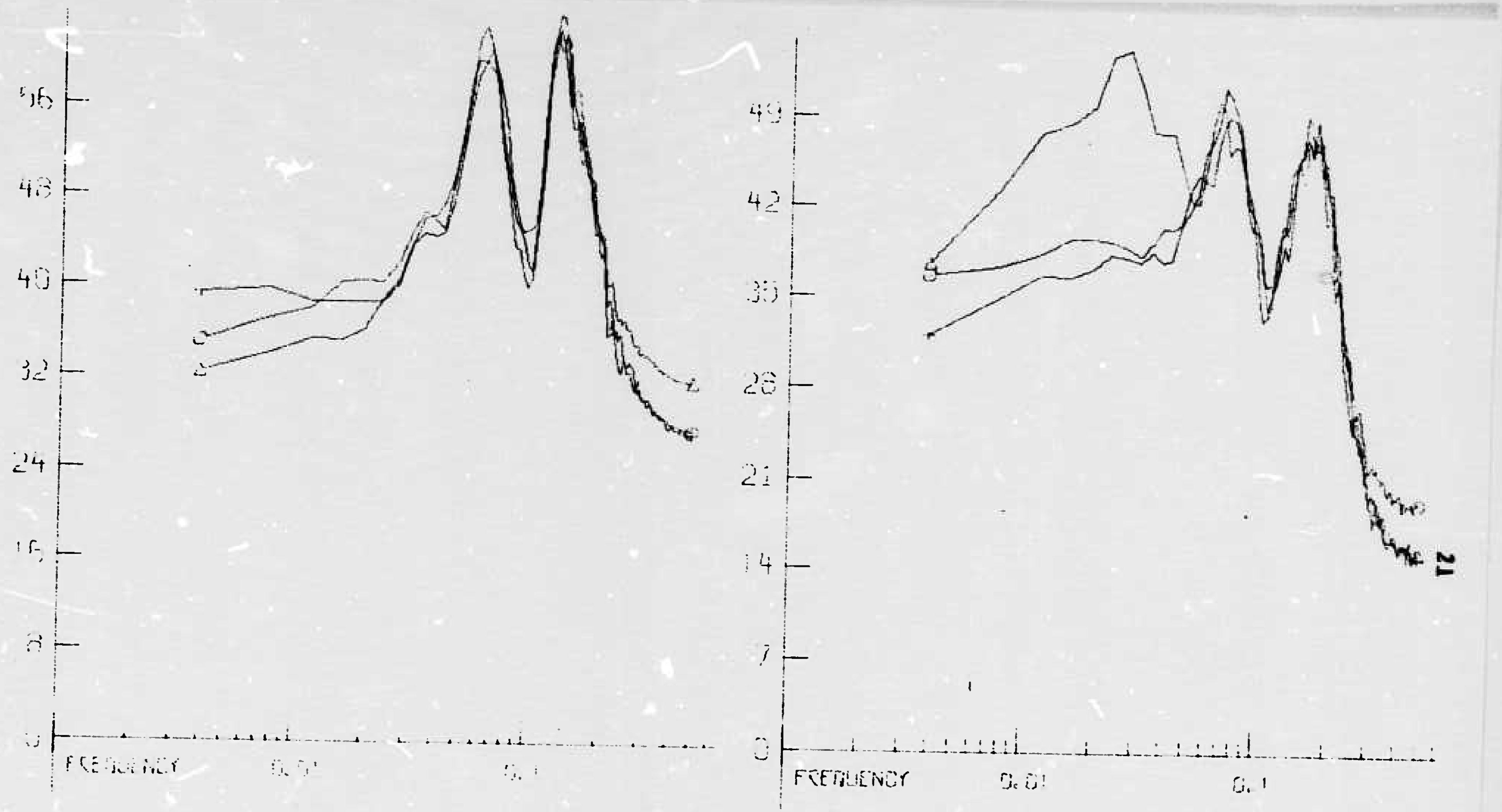


Fig. 7. Power spectral density (dB rel to 1 nm^2 at 0.050 Hz) at 19 Oct. 1972 0900 (right) and 1400 for three different NORSAR LPZ-components. The estimates are based on 5 nonoverlapping blocks of 256 samples each of 1Hz data.

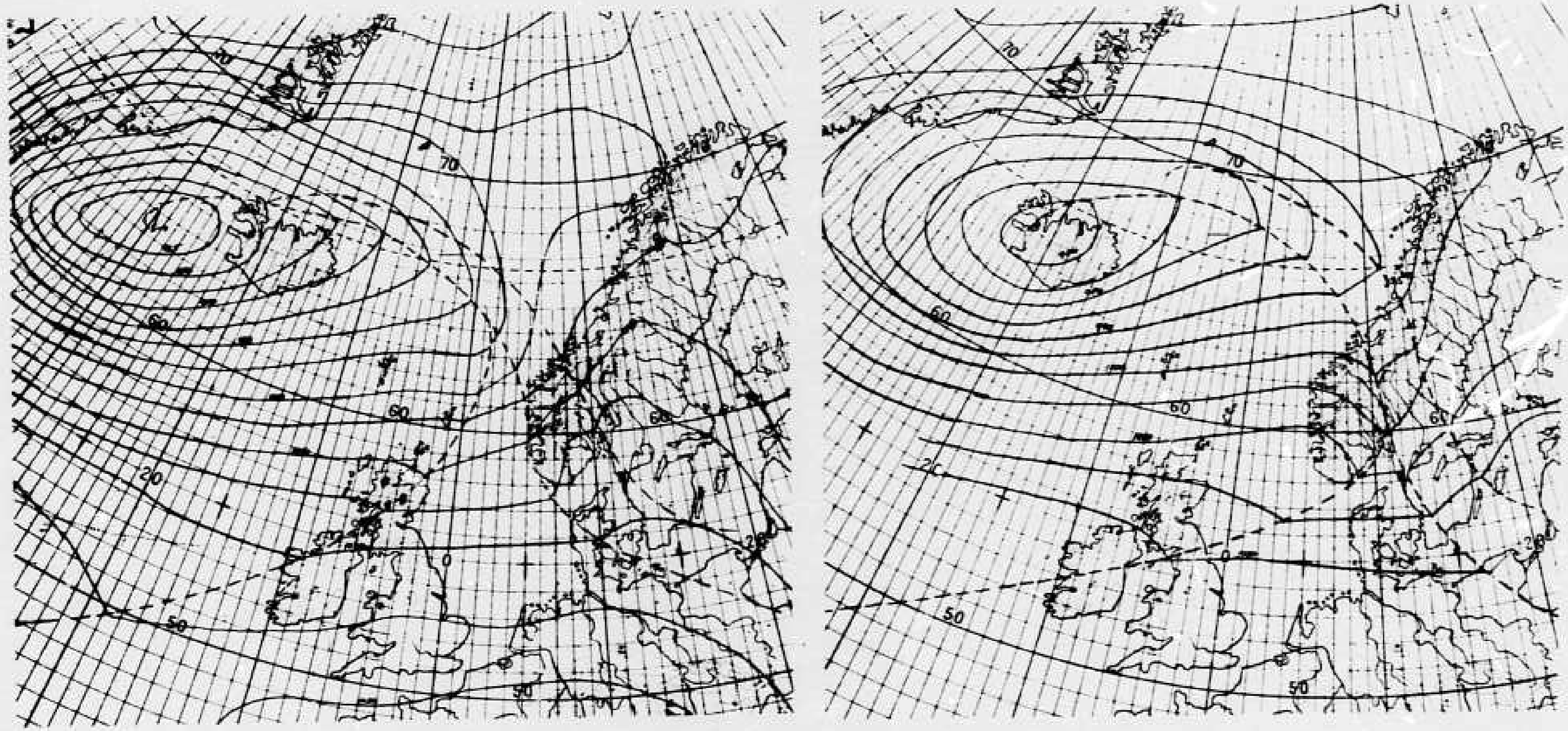


Fig. 8. Weather maps 6 Nov. 1972, 1200 and 2100.

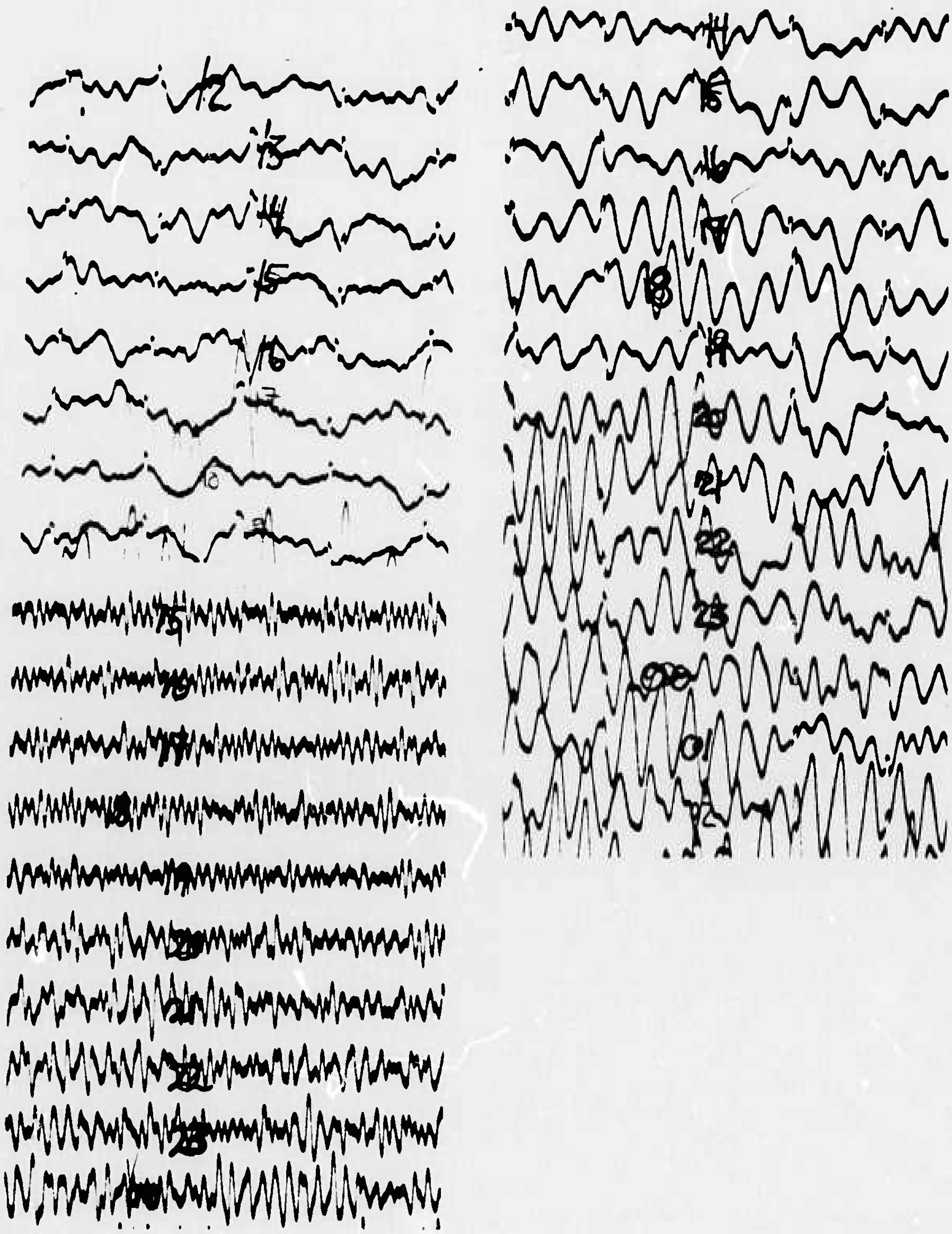


Fig. 9. Kongsberg LPZ High gain recordings 5 Nov. (top, left), 6 Nov. (top, right) and Low gain 6 Nov. 1972 (bottom left).

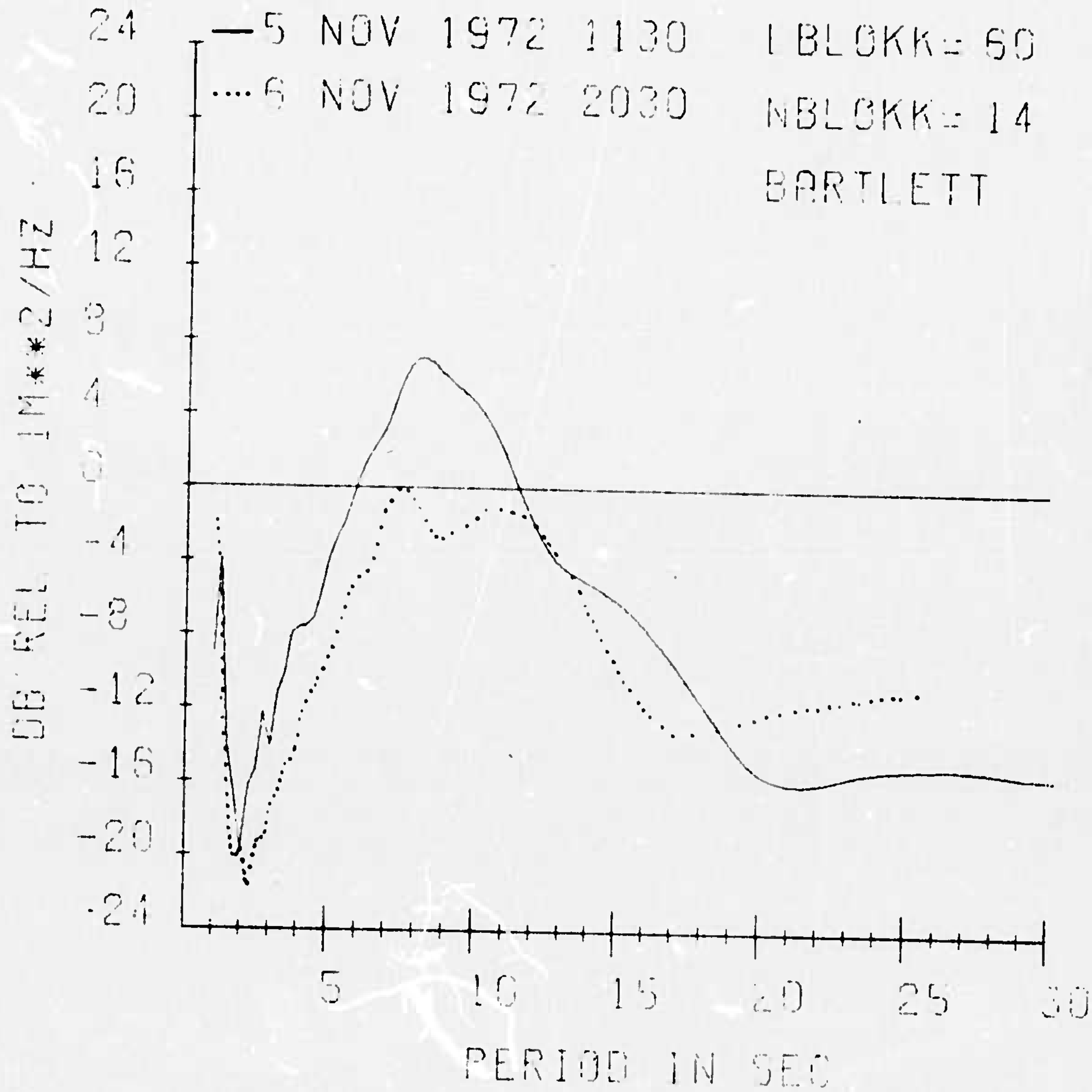


Fig. 10. Sea wave power spectra Utsira 5 and 6 Nov. 1972.

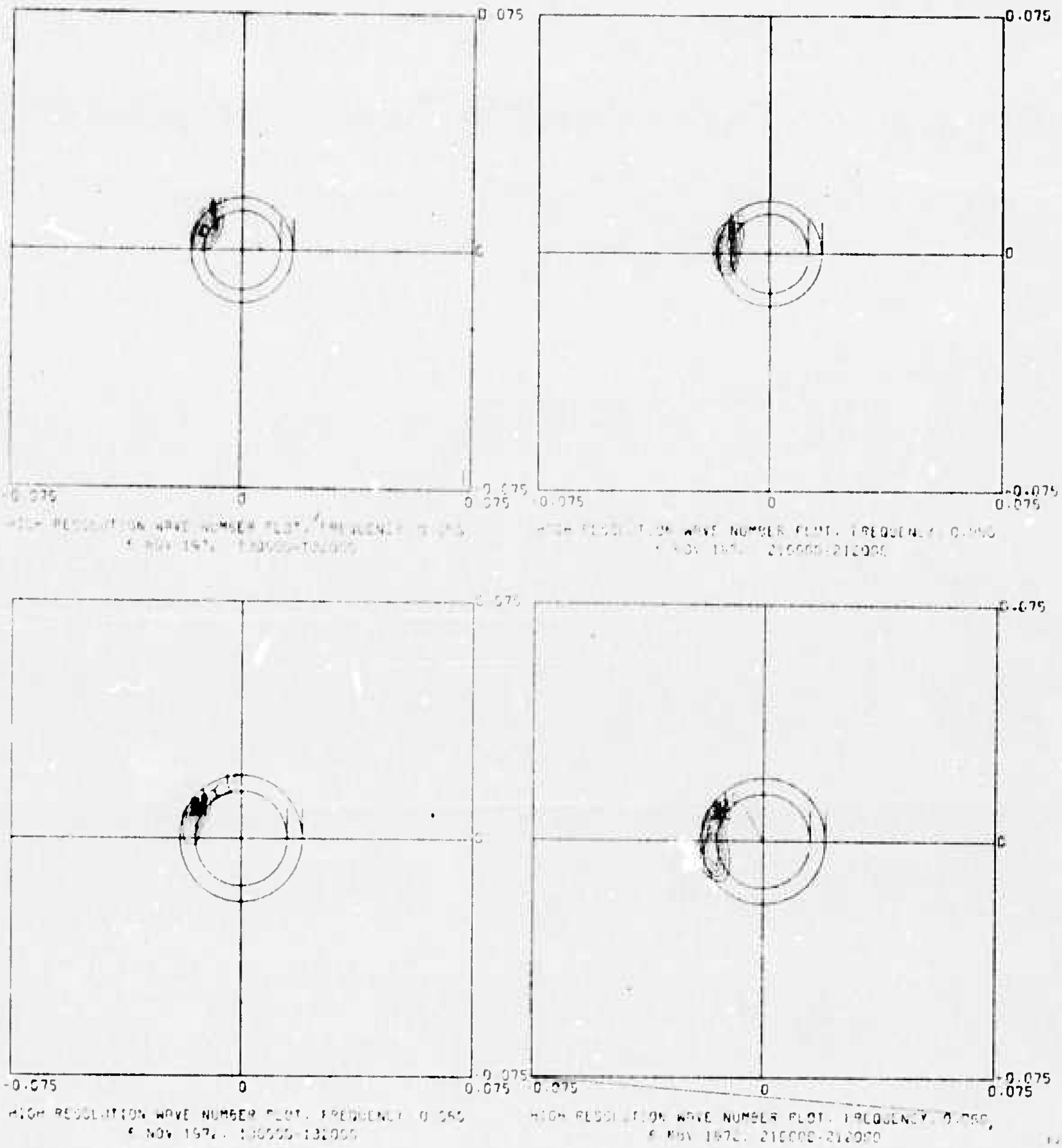


Fig. 11. NORSAR LPZ wavenumber spectra 6 Nov. 1972.

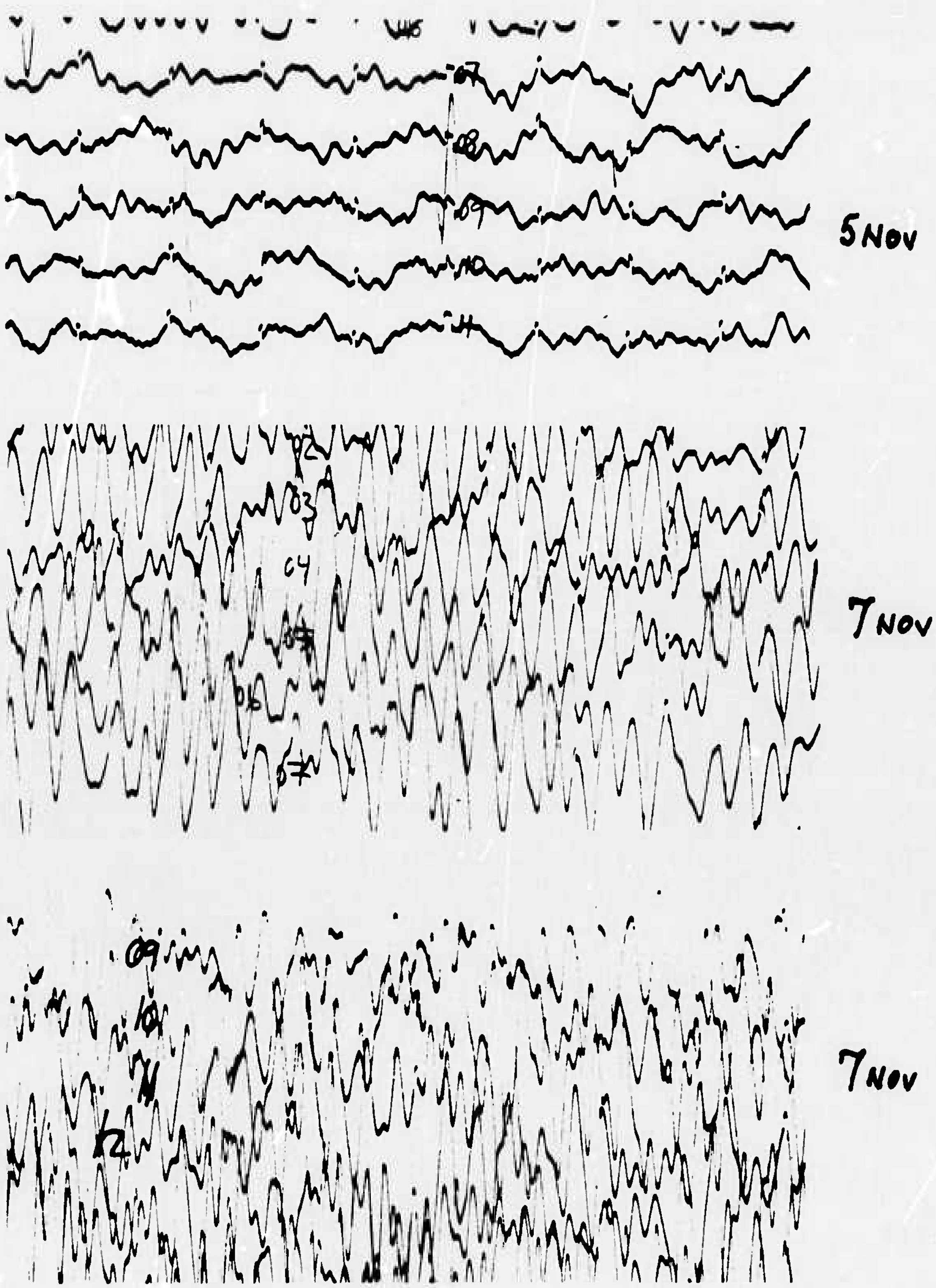


Fig. 12. Top to bottom: Kongsberg LPZ High gain recordings 5 and 7 Nov. 1972.

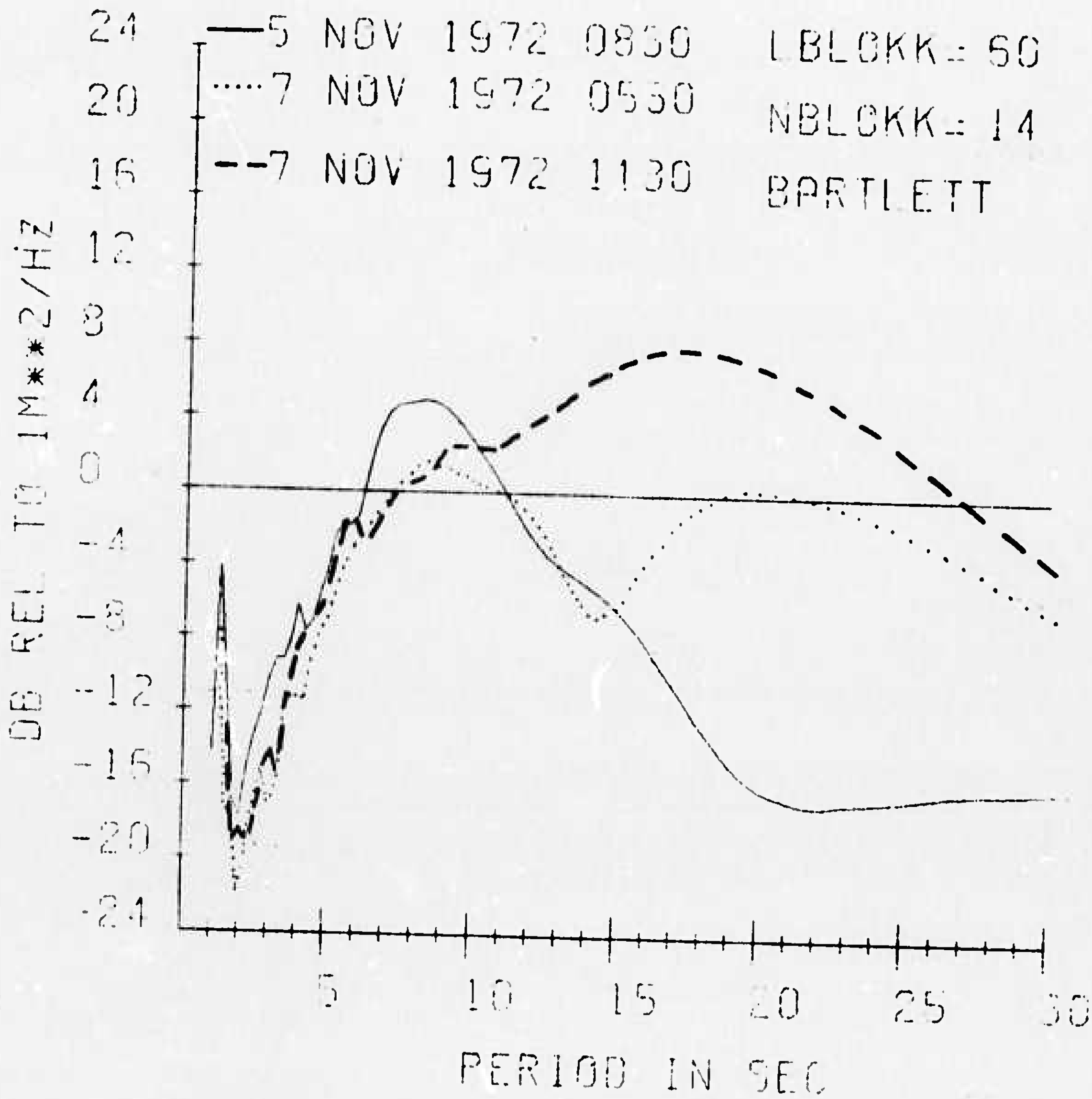


Fig. 13. Sea wave power spectra at Utsira 5 and 7 Nov. 1972.

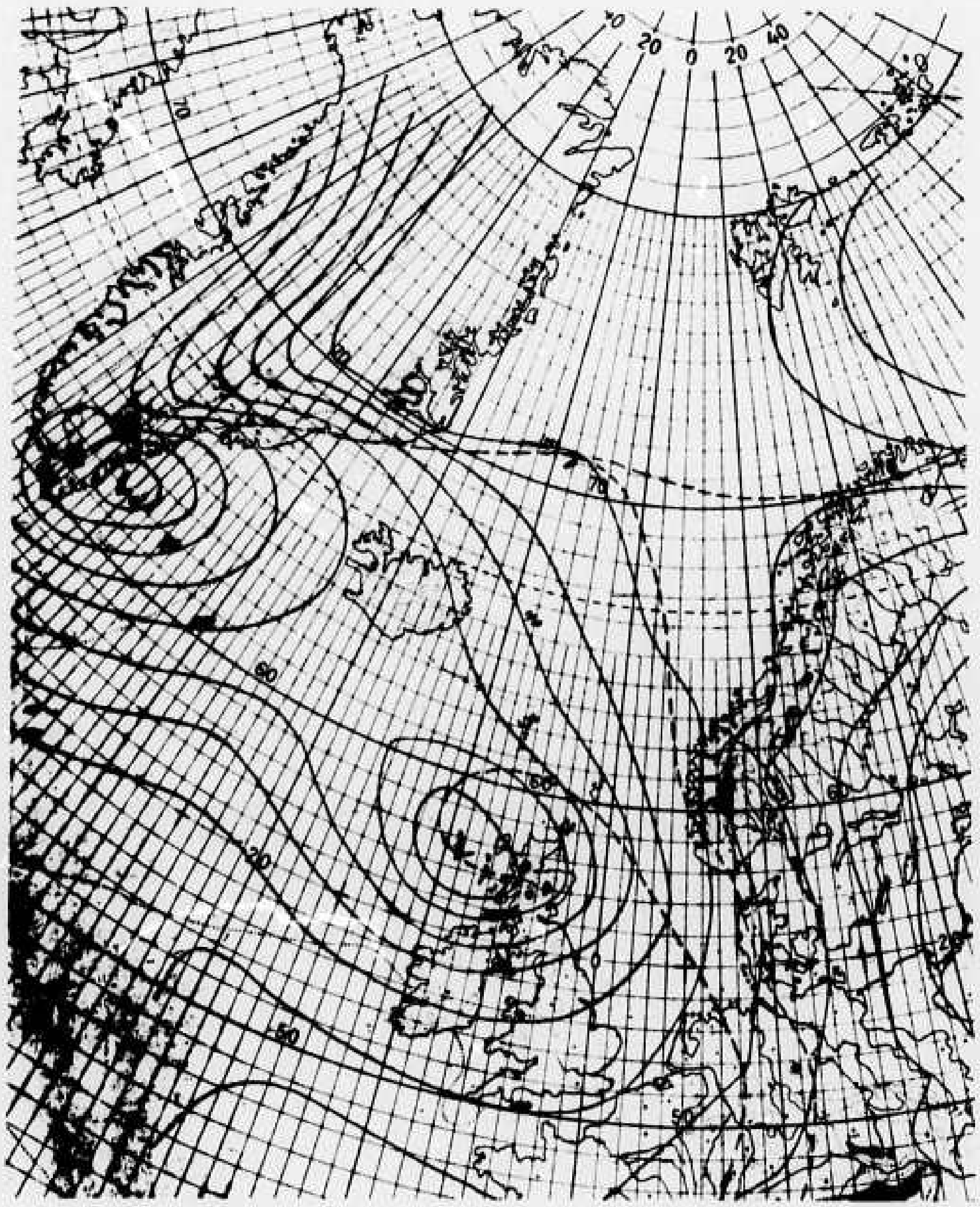


Fig. 14. Weather map 15 Jan. 1973, 1800.

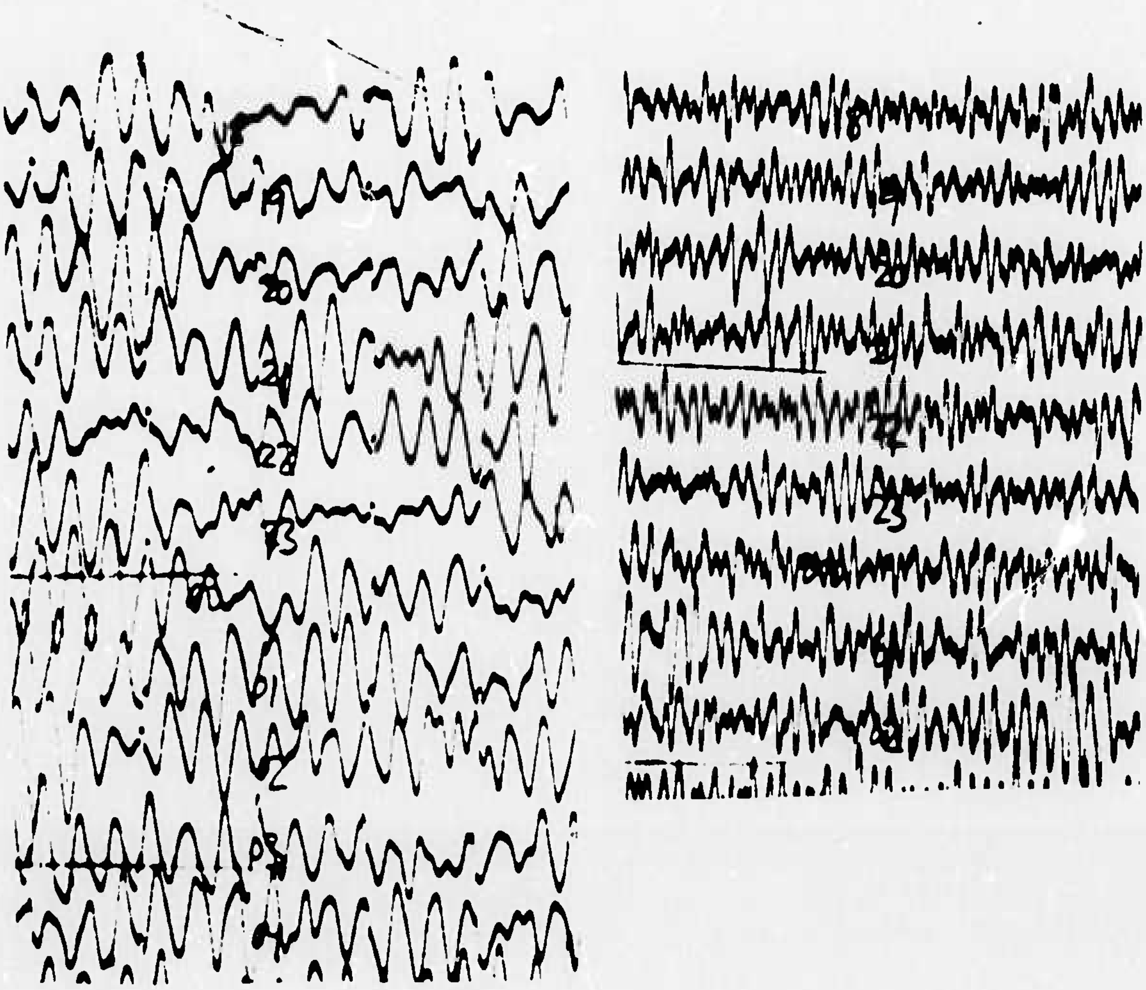


Fig. 15. Kongsberg LPZ recordings 15 Jan. 1973. High gain to the left.

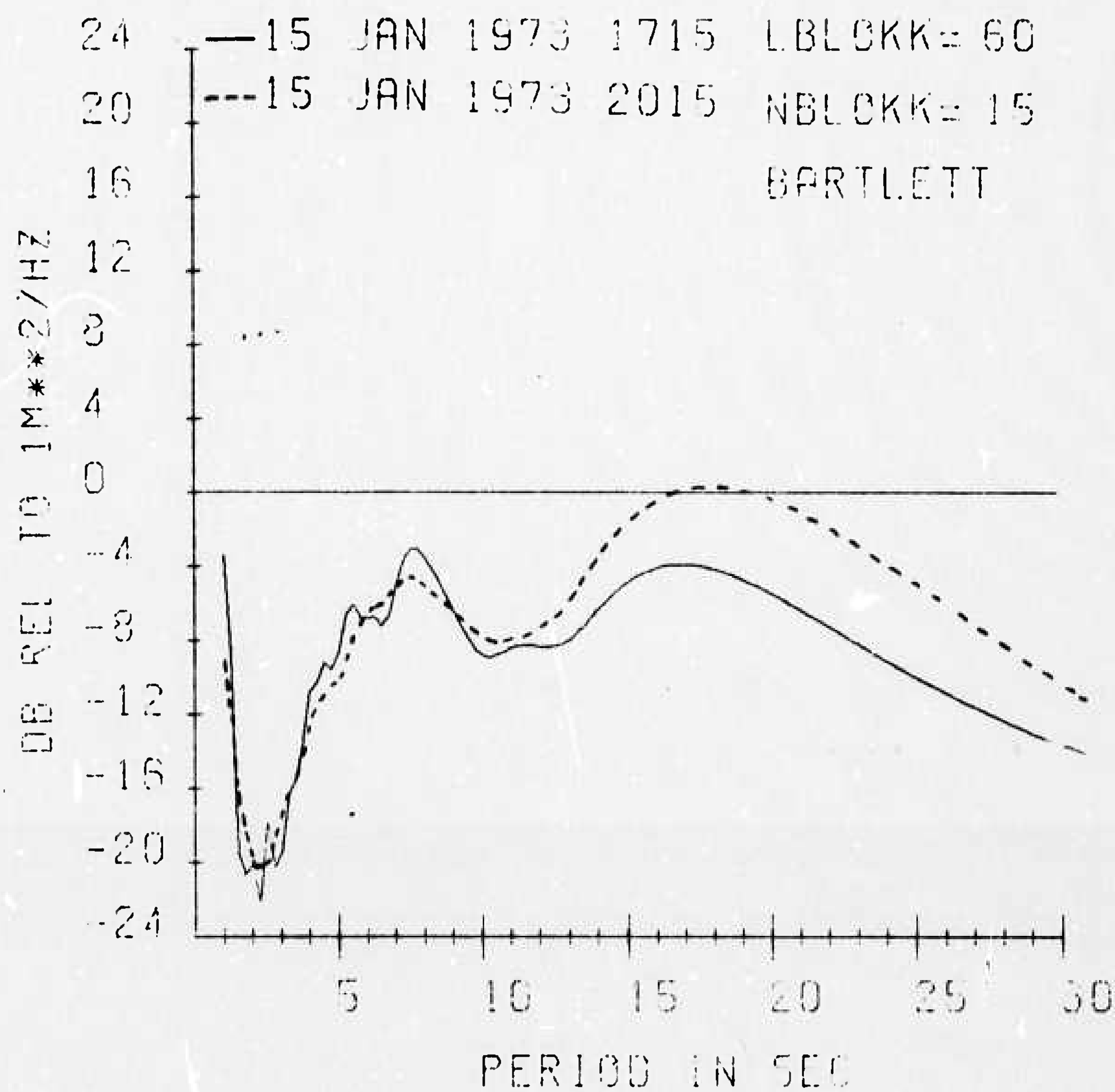


Fig. 16. Sea wave power spectra Utsira 15 Jan. 1973.

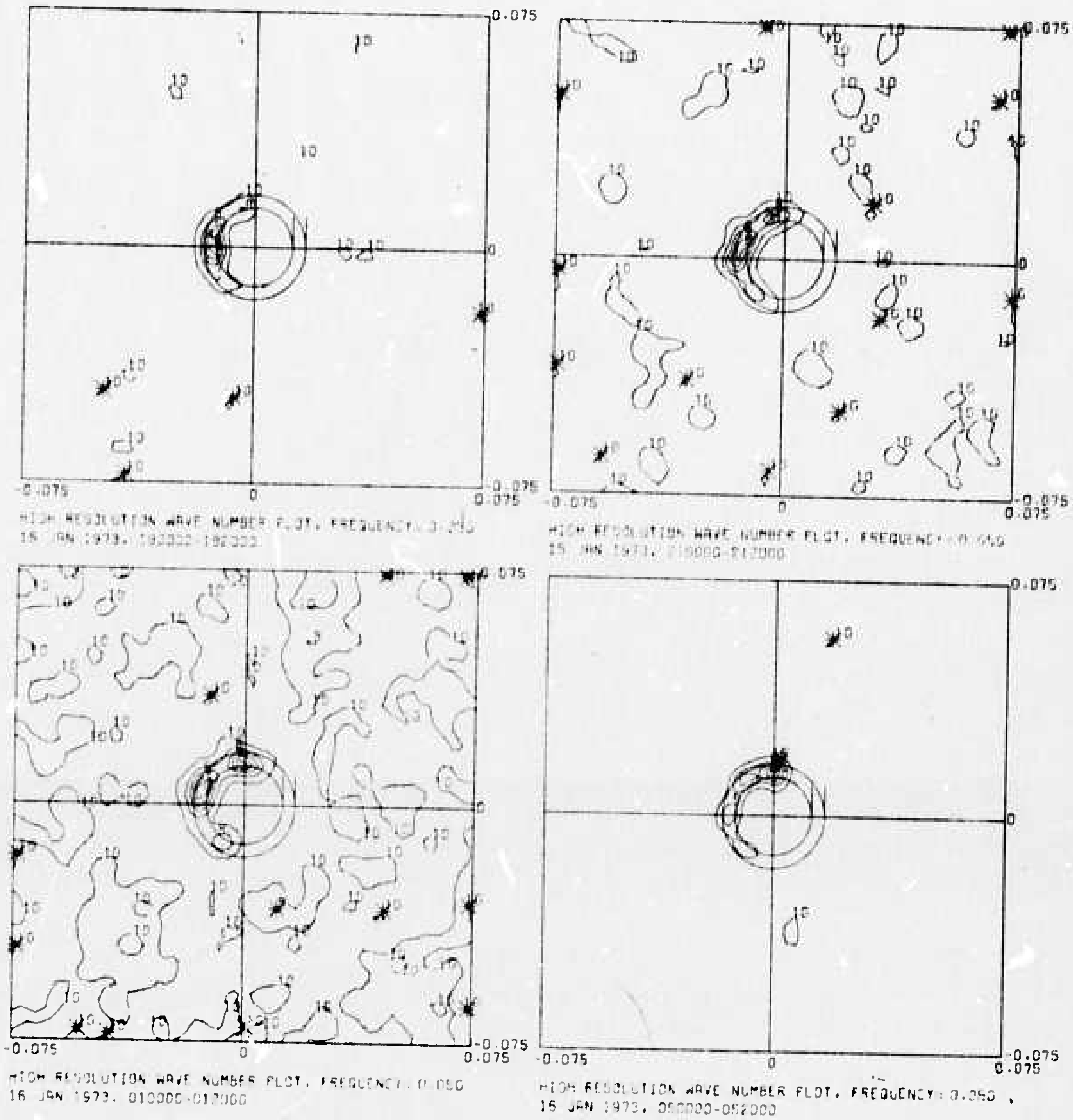


Fig. 17. NORSAR LPZ wavenumber spectra 15 and 16 Jan. 1973.

0900 1500

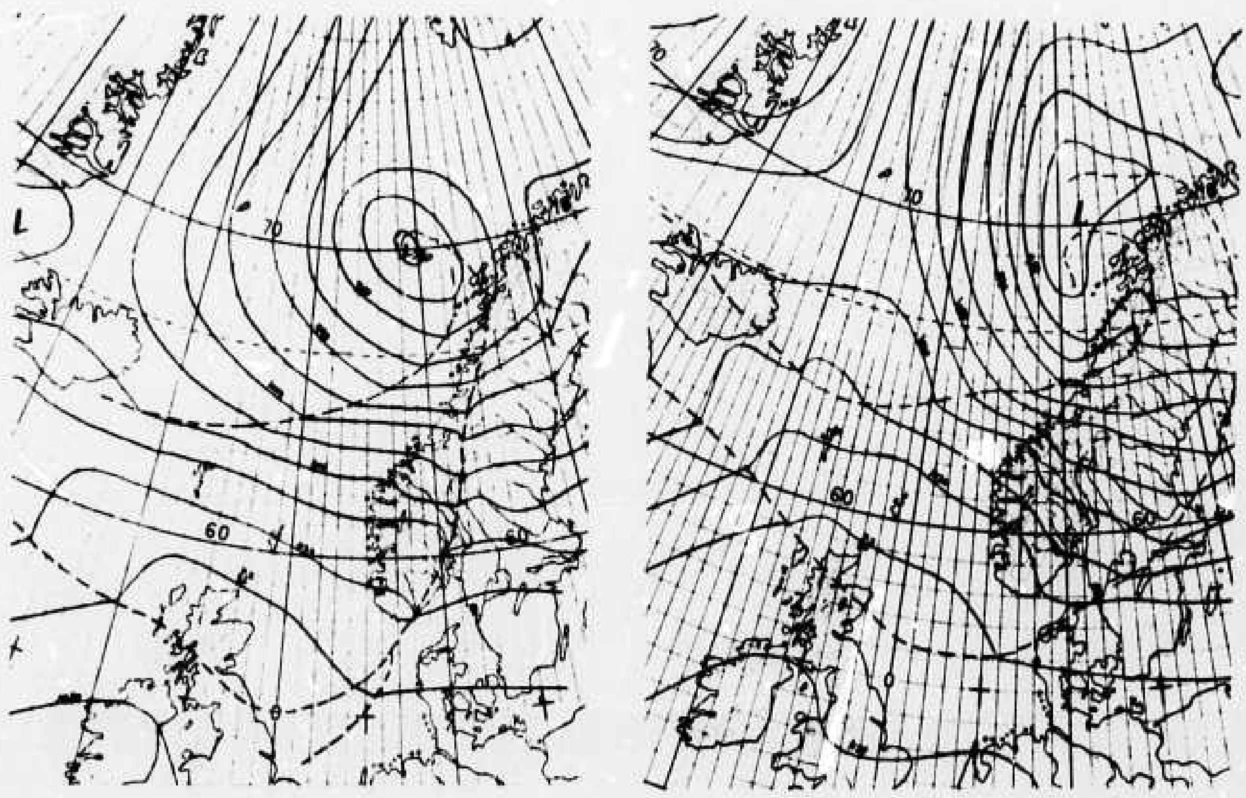


Fig. 18. Weather maps 2 Feb. 1973, 0900 and 1500.

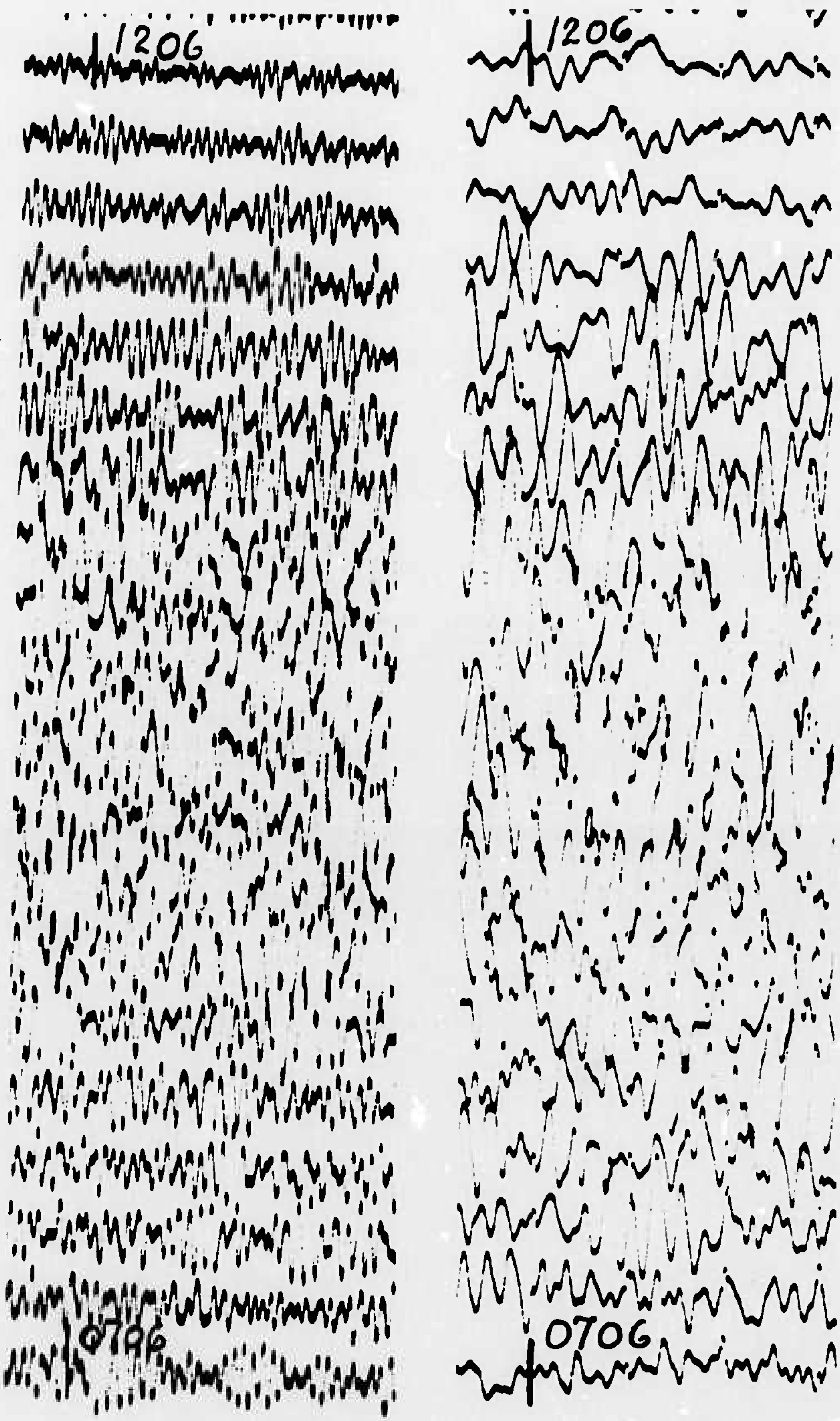


Fig. 19. Kongsberg LP recordings 2-3 Feb. 1973. Low gain EW to the left and High gain Z to the right.

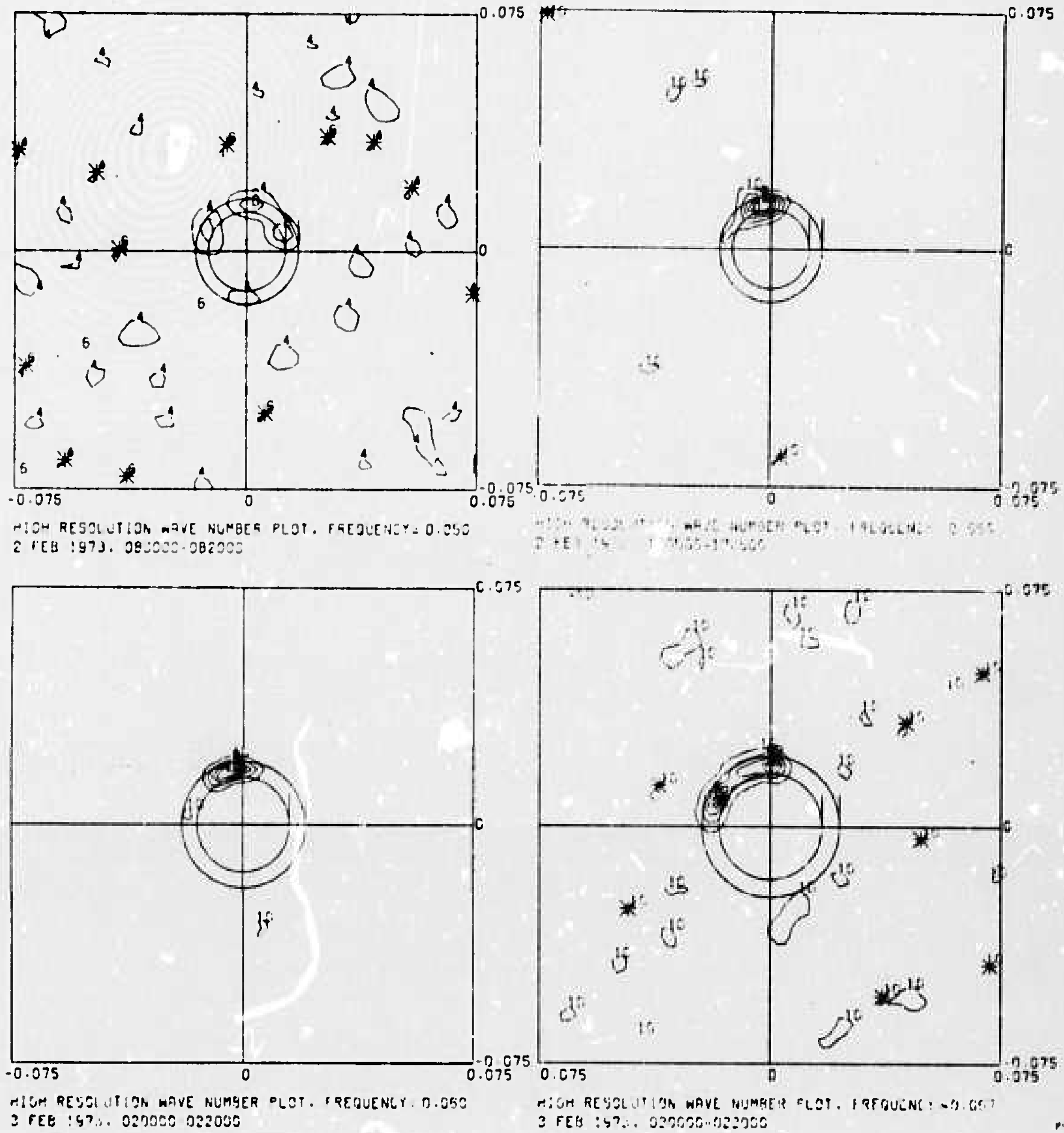


Fig. 20. NORSAR LPZ wavenumber spectra 2-3 Feb. 1973.

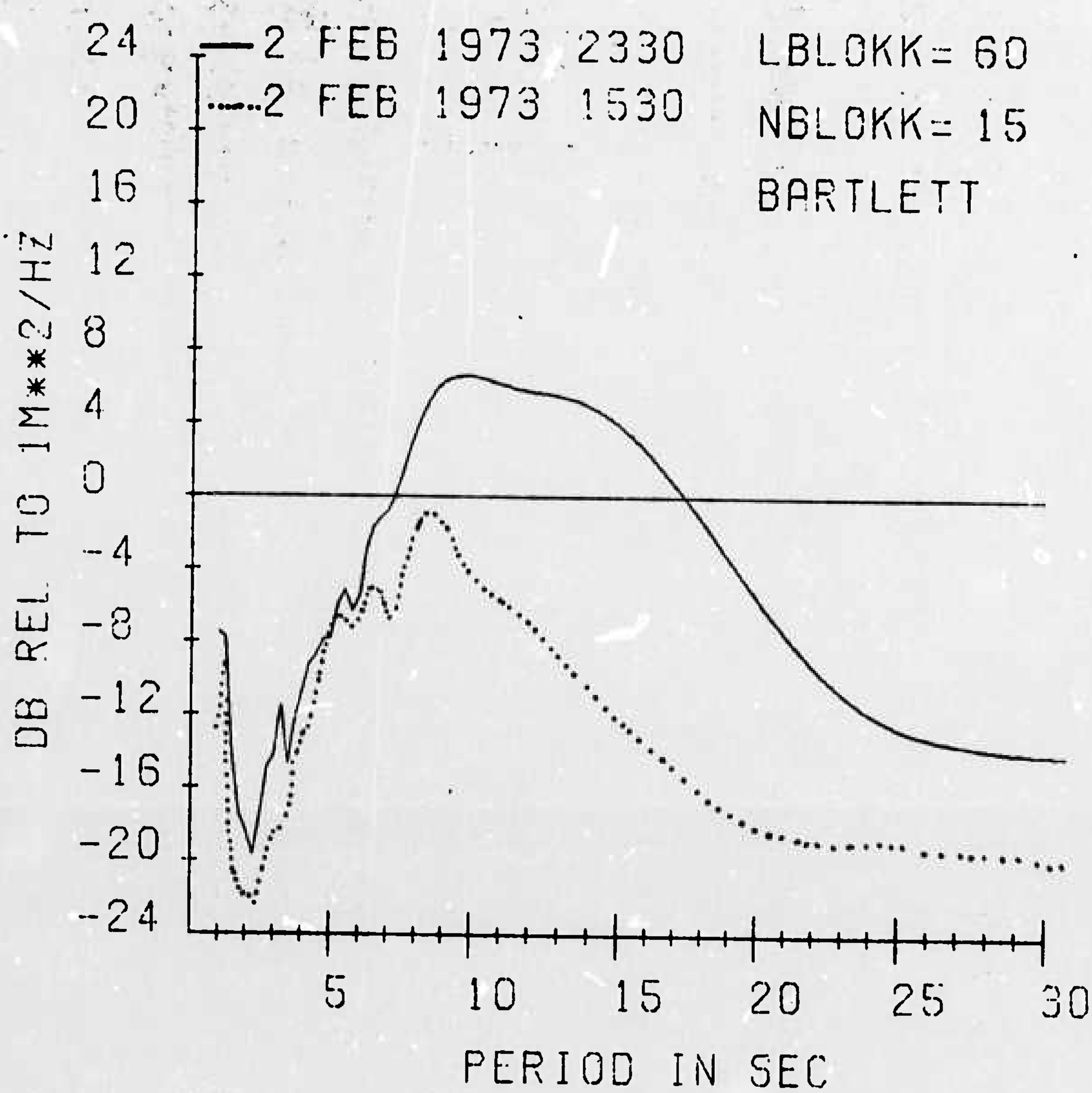
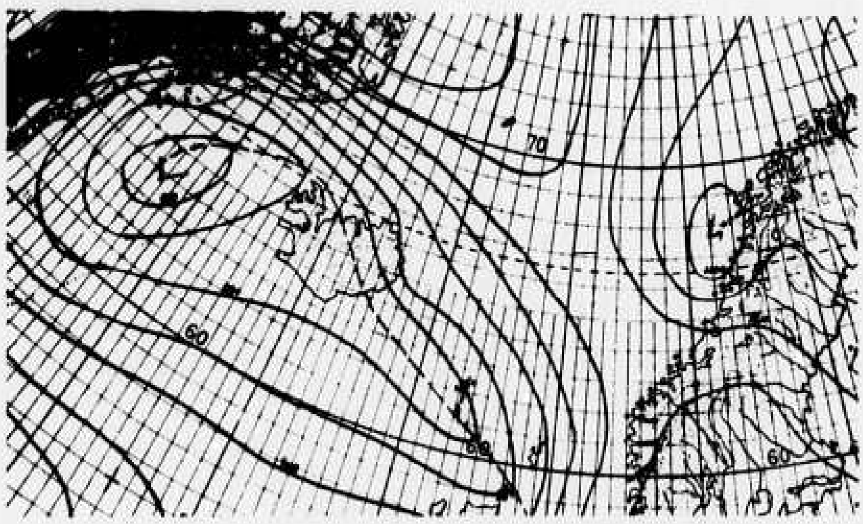


Fig. 21. Sea wave power spectrum Utsira 2 Feb. 1973.

4 Apr. 0600



5 Apr. 0000

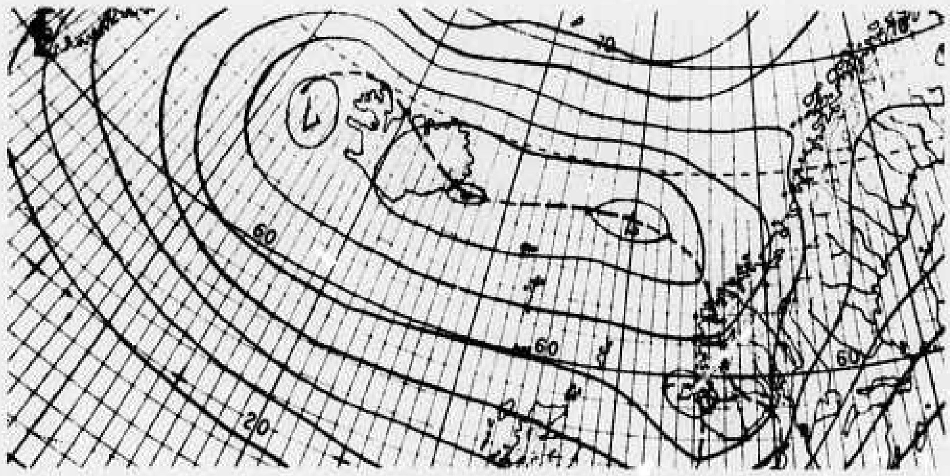


Fig. 22. Weather map 4 Apr. 1973, 0600 and 5 Apr. 1973, 0000.

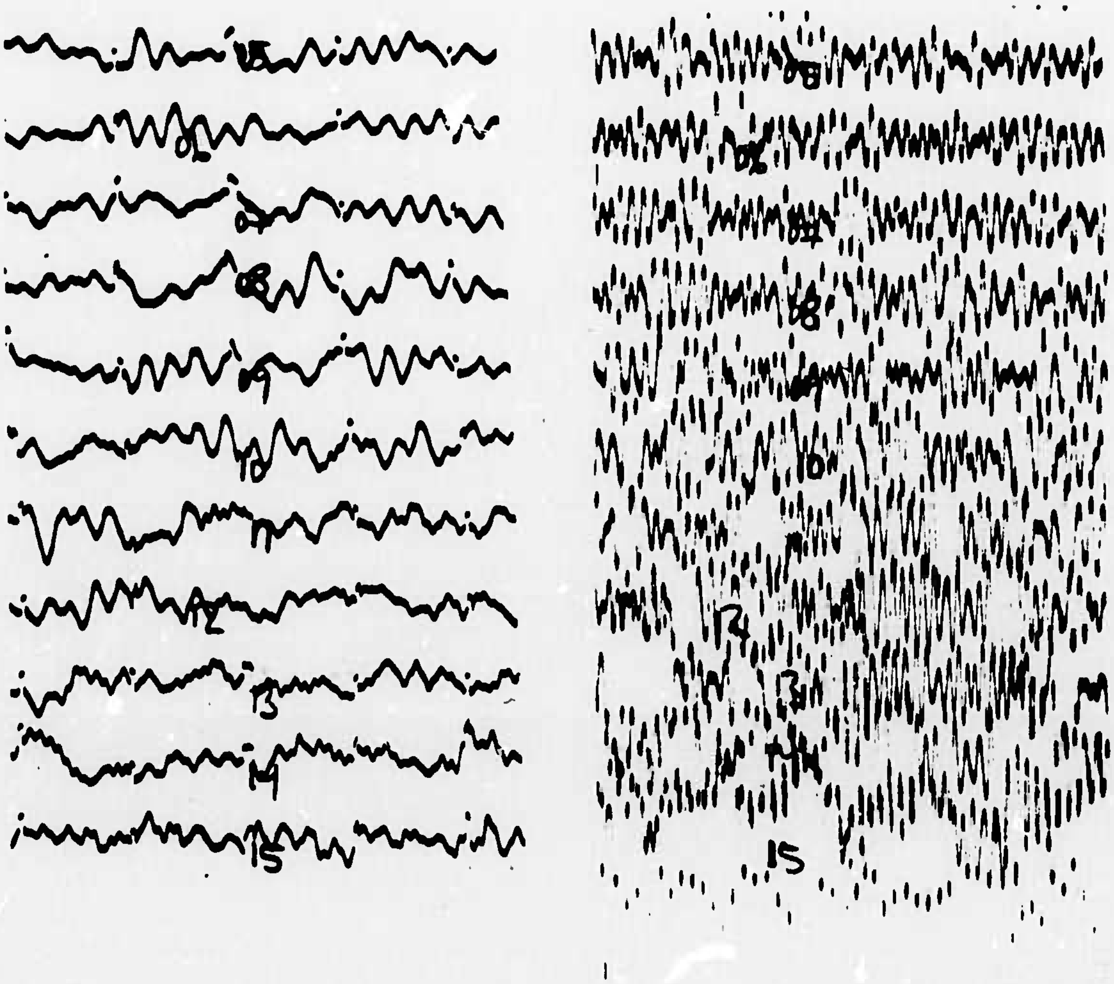


Fig. 23. Kongsberg LPZ recordings 4 Apr. 1973. High gain to the left. Low gain to the right.

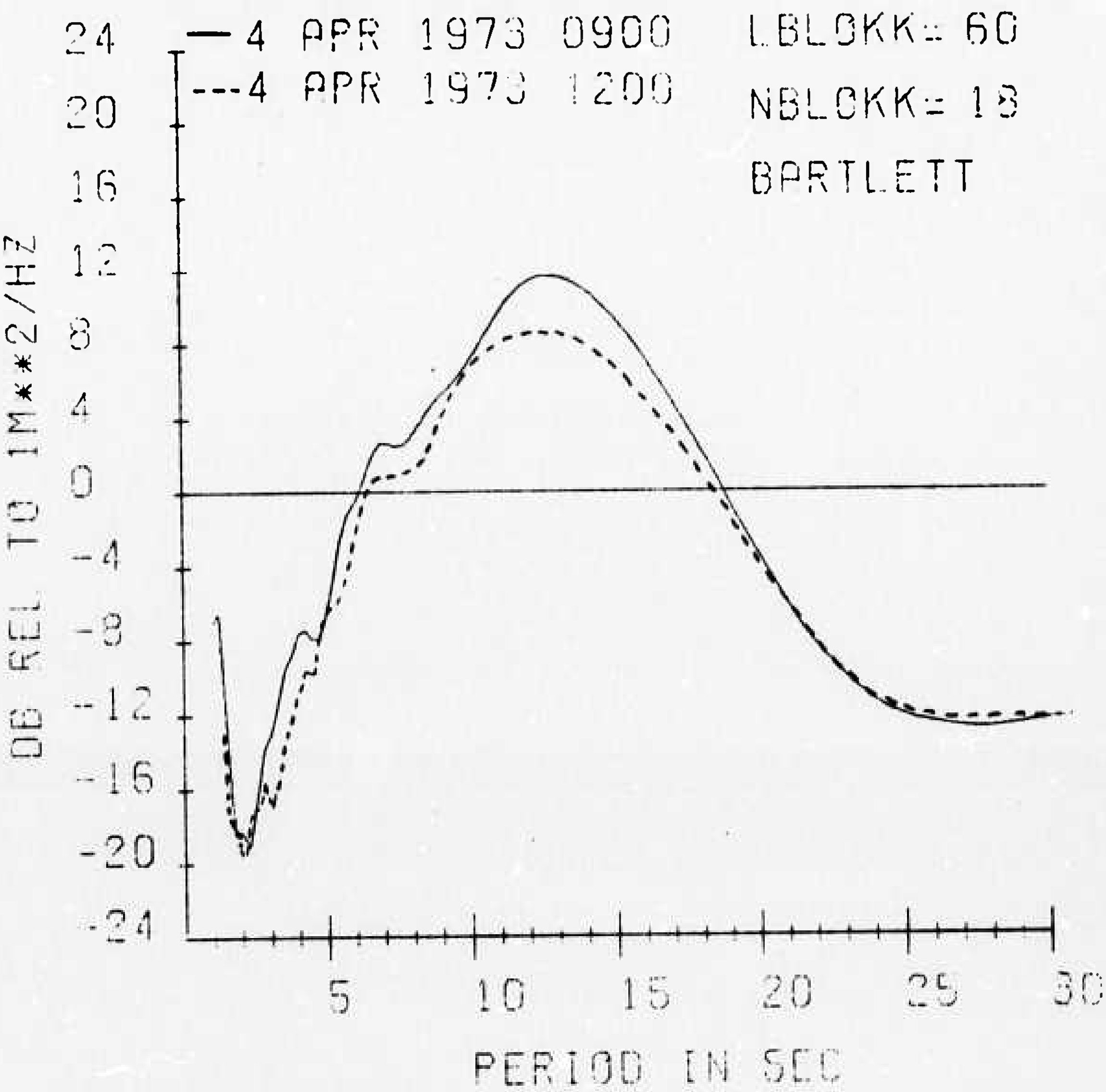


Fig. 24. Sea wave power spectra Halten 4 Apr. 1973.

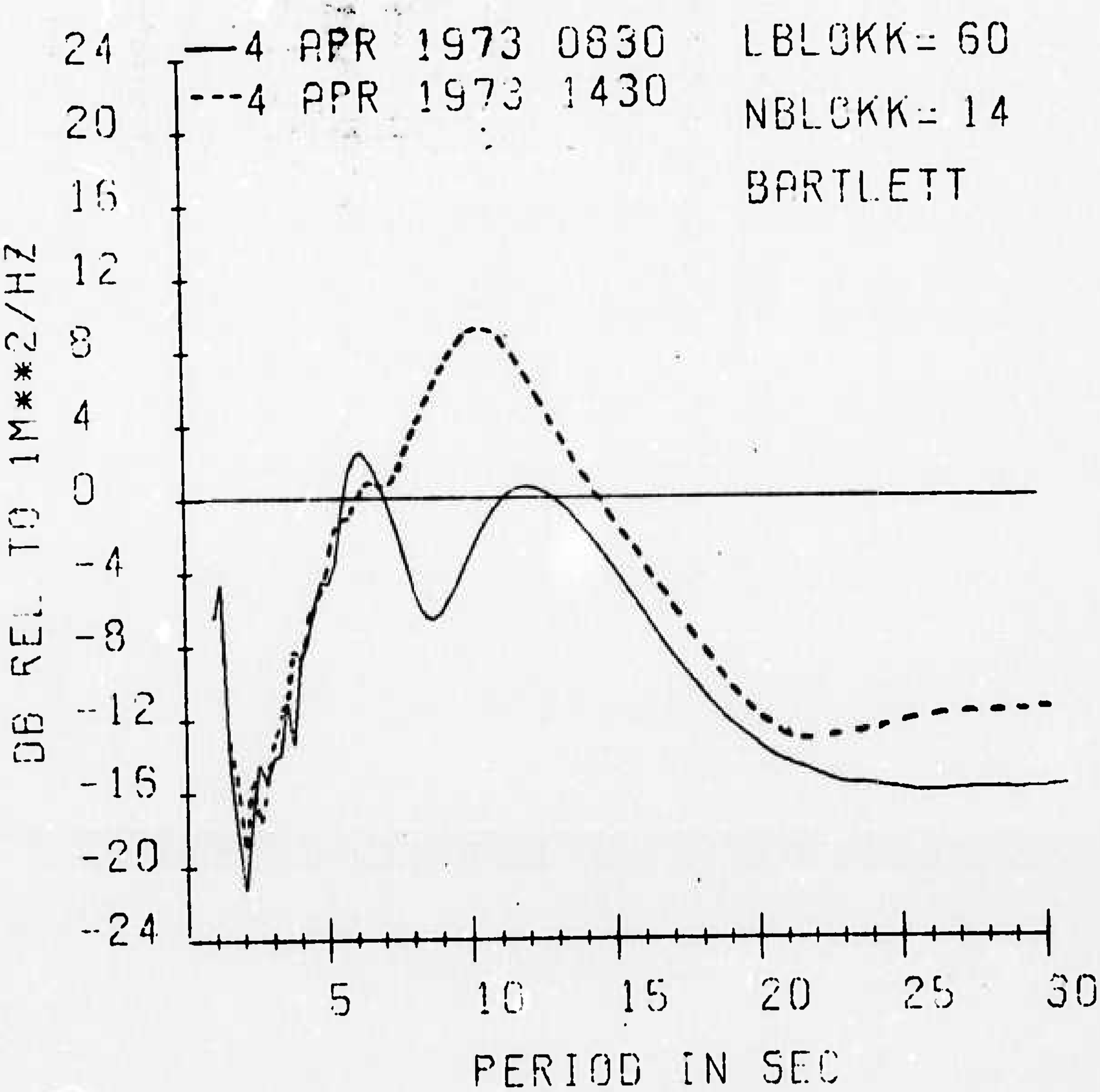


Fig. 25. Sea wave power spectra Utsira 4 Apr. 1973.

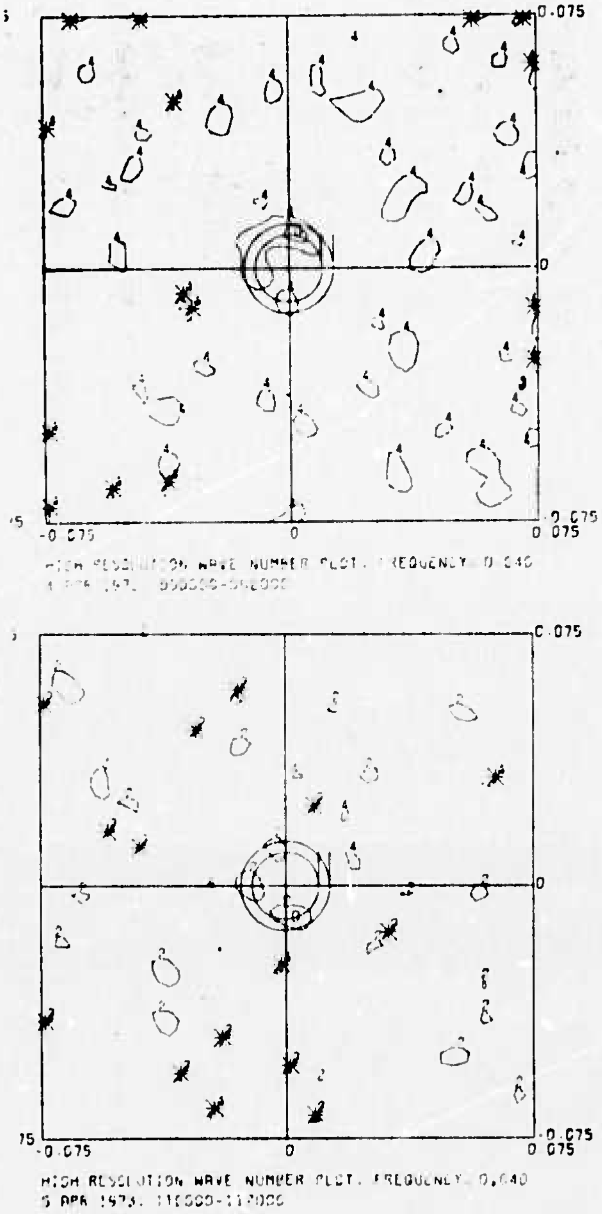


Fig. 26. NORSAR LPZ wavenumber spectra 4-5 Apr. 1973.

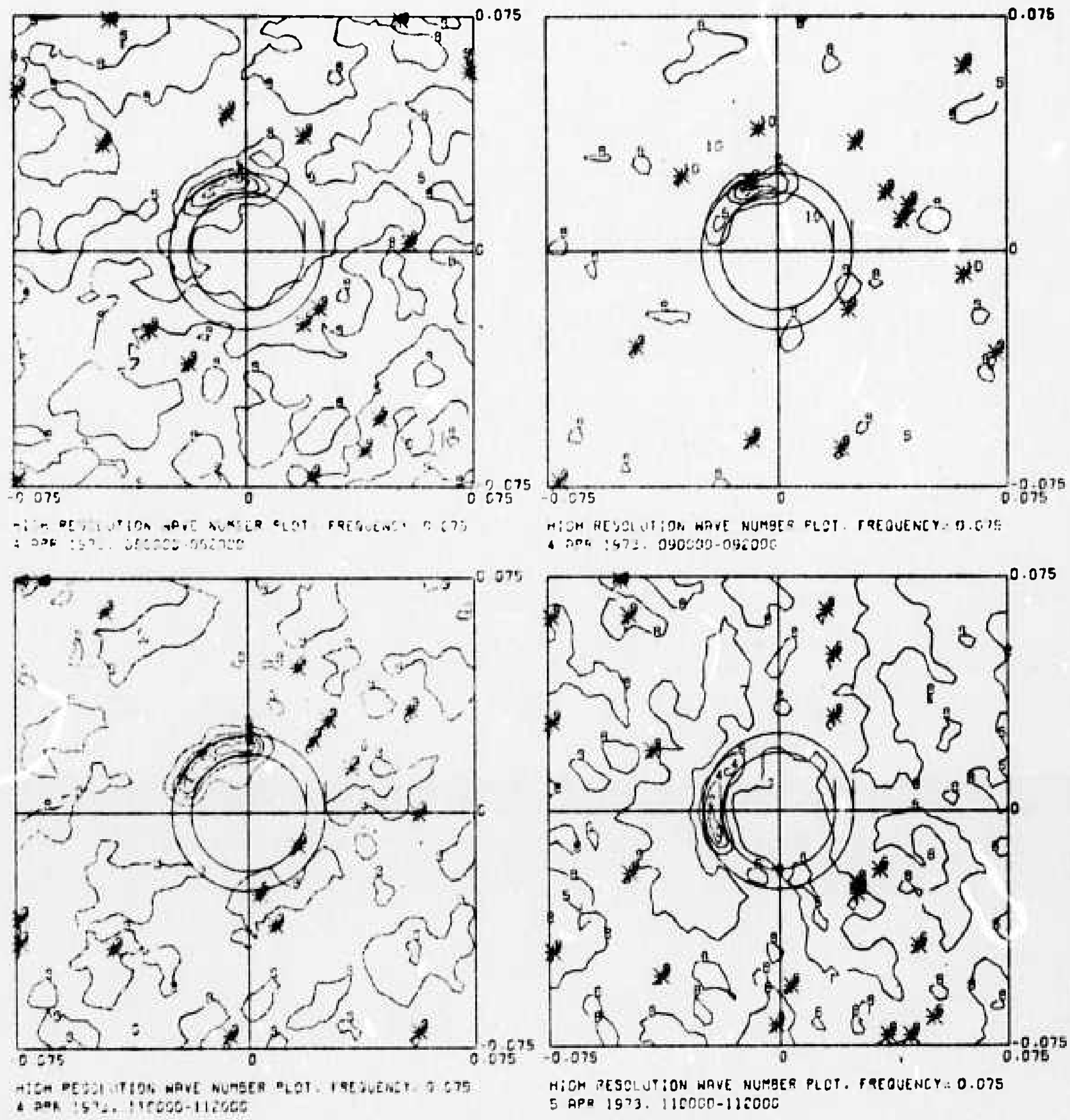


Fig. 27. NORSAR LPZ wavenumber spectra 4-5 Apr. 1973.